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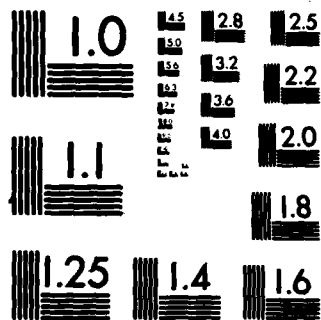
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Figure 1



MICROCOPY RESOLUTION TEST CHART
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FEASIBILITY OF OFFSET CARRIER SYSTEMS FOR AIR TRAFFIC CONTROL

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AMAF Industries, Inc.
103 Sterrett Building
Columbia, Maryland 21044



September 1979
Interim Report

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16. Abstract <p>A review of offset carrier systems development and history is provided for insight into problems that can affect air traffic control. An amplitude modulated offset carrier system is discussed as a special case of normal AM superheterodyne communications. Potential problems of heterodyne beats that can occur above, below and in the audio band are noted. Potential audio phase delay distortion between two or more signals is discussed with respect to remote control line problems and to differential propagation delay problems. The difficulty in combining audio from separate remote receivers is discussed. Target acquisition model contours are provided for the four air traffic sectors to be used in the remainder of the study.</p>			
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
y	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
sq in	square inches	6.5	square centimeters	cm ²
sq ft	square feet	0.09	square meters	m ²
sq yd	square yards	0.8	square meters	m ²
sq mi	square miles	2.6	square kilometers	km ²
ac	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
cup	teaspoons	5	milliliters	ml
fl oz	tablespoons	15	milliliters	ml
qt	fluid ounces	30	milliliters	ml
p	cup	0.24	liters	l
qt	pints	0.47	liters	l
gal	quarts	0.95	liters	l
cu ft	gallons	3.8	liters	l
cu yd	cubic feet	0.03	cubic meters	m ³
	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 m = 2.54 inches. For other exact conversions and more detailed tables, see NBS Misc. Publ. 216, Units of Length and Mass, Pub. 52.35, SI Conversions No. C13.10-206.

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
mi	miles	1.1	yards	y
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (weight)				
g	grams	0.05	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	cu ft
m ³	cubic meters	1.3	cubic yards	cu yd
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

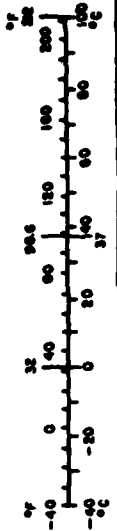


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1.0 PURPOSE

The purpose of this document is to provide an interim report on the first phase of the investigation of the feasibility of offset carrier systems for Air Traffic Control (ATC). The overall investigation is to be conducted in three phases.

a. In Phase 1 the principles of offset carrier theory and practices were examined and a description provided as to how and how well such a system may apply to FAA ATC air-ground communication for Air Route Control Center (ARTCC) and Flight Service Station (FSS) use. The technical and operational control principles of the offset carrier system are postulated to be within the National Airspace System (NAS) with the compatibility or incompatibility characterized.

b. In Phase 2 information on FAA and other trials of offset carrier systems and other multiple outlet system approaches is to be assimilated, reviewed and correlated. Particular consideration will be given to:

(1) Communication deficiencies based on existing needs and initial requirements.

(2) Identification of system design deficiencies will be made to determine airborne or ground subsystem characteristics not compatible with a multiple outlet system.

(3) Identification of relationships with Phase 1 will be made and those found to be common to any multiple outlet system will be examined.

c. In Phase 3 an engineering analysis will be made of major problems (existing and potential) in implementation and use of an offset carrier system. Included will be:

(1) All the considerations and findings of Phases 1 and 2.

(2) Configuration, design or operational detail sufficient only to define a problem (known or anticipated).

(3) An identification of possible solutions to unresolved areas of previous FAA concern to include at least audio phasing, holes in air-ground coverage, heterodyning, and signal processor use.

(4) A discussion of the applicability of conventional FAA equipments (AN/GRR-23, AN/GRT-21 and conventional audio equipment of a typical RCAG, ARTCC, or FSS facility) in an offset carrier system.

(5) Consideration of airborne terminals will be limited to the equipment performance characteristics of not more than 6 or less than 4 air-line and general aviation terminals.

(6) Suggestions will be made concerning possible new equipment, new techniques or modifications that seem practical to use in the NAS air-ground communication system.

1.1 CONSTRAINTS

The constraints listed below are applicable to all three phases.

a. The investigation will be limited to four configurations using two and three outlets separated by a minimum of 40 statute miles and a maximum of 140 statute miles.

b. The investigation is for vhf frequencies only, even though uhf correlation exists.

c. Applicable standards and performance criteria are those obtained from the Federal Register, U.S. National Aviation Standard for the VHF Air-ground Communication System and FAA handbooks.

d. Only minimum analysis is applied to the operational impact of such factors as aircraft density, channel loading, communications workload and the probabilities of interference from elements outside the offset system.

e. Experimentation or testing is not a part of the investigation.

f. The investigation will assist in determining the feasibility of an offset carrier system, not determine the feasibility.

1.2 APPROACH

The Phase 1 investigation was accomplished by a search for existing information on offset carrier system theory and operation. The data acquired was reviewed and analyzed to provide the basis for the theory and history of offset carrier operation. This background was then applied to the identification and characterization of how offset carrier operation could be applied to the four FAA vhf outlet configurations to be used in the investigation. The data sources reviewed or contacted were:

a. ORBIT Data Bases (NTIS and INSPEC files).

b. DOT Library (FOB 10A Branch).

c. The R.E. Gibson Library, Johns Hopkins University, Applied Physics Laboratory.

d. Aeronautical Radio, Inc. (ARINC).

e. DOD Electromagnetic Compatibility Analysis Center (ECAC).

f. Institute of Telecommunications Sciences (ITS).

g. U.K. Mission to the FAA.

h. U.K. Civil Aviation Authority.

i. Various FAA offices involved with frequency management and air-ground communications at FAA Headquarters, the Southwest region, Rocky Mountain region, and Western region.

2.0 OFFSET CARRIER HISTORY AND THEORY

Offset carrier systems developed from the published results of experimentation conducted in the early 1940s by J.R. Brinkley and others. The theory is really the theory of heterodyne/super heterodyne radio, but with multiple signals applied as inputs rather than the normal single signal. The early test results were promising enough that both the ARINC and U.K. multi-carrier systems were developed and continue in use today. Difficulties and requirements for modifications have been encountered as described in the following paragraphs. The section on theory covers the design engineering necessary for an offset carrier system in terms of offset spacing, transmitter stability, and delay factors.

2.1 EARLY HISTORY

No published reference was found prior to J.R. Brinkley's 1946 paper, "A Method of Increasing the Range of V.H.F. Communications Systems by Multi-carrier Amplitude Modulation".^{1/} Brinkley had been investigating means for providing vhf land mobile coverage for a large geographic area in England during World War II. A two station scheme using frequency modulation with the stations on the same nominal carrier frequency was attempted and discarded. A synchronized frequency amplitude modulation using multiple transmitters was analyzed. While theoretically possible, this method was eliminated due to the impracticability of maintaining synchronized carrier frequencies and the standing wave patterns that would exist from identical carriers radiated from separate antennas. This led to the investigation of a multiple carrier amplitude modulation system with the carrier frequencies separated enough to avoid unwanted audible beats, but with the carriers and sidebands still within the receiver pass band.^{1/} A two station test showed that the modulation applied to the carriers should be equal in amplitude and have the same phase. Unequal amplitudes produced a flutter effect. Modulations not in phase produced both flutter and distortion.

In a three station test, no multicarrier distortion products were detected. Both tests showed the multicarrier transmission coverage area was greater than the sum of the areas covered by single carrier operation. Reception coverage area was approximately equal to three times that of a single station in the three station test. A fourth order term of the form $2f_0 - (f_0 + \Delta) - (f_0 - \Delta)$ did cause a faint heterodyne whistle in about 10% of the three carrier test area. The beat was about 30-40 db below the signal level and was eliminated by adjusting the transmitter crystals to provide nearly identical offsets.^{1/} The success of the initial offset carrier tests led to

^{1/} Brinkley, J.R., A Method of Increasing the Range of V.H.F. Communications Systems by Multi-carrier Amplitude Modulation, the Journal of the British Institution of Radio Engineers, Vol. 93, No. 23, May 1946.

the use of vhf amplitude modulated offset carrier systems in the U.K. police and fire department networks.2/ The U.K. Ministry of Civil Aviation also used the offset carrier system in the Climax network for Air Traffic Control.3/

2.2 THE ARINC SYSTEM

About the same time as the U.K. offset carrier ATC system was being developed, a U.S. system for airline operational control was also developed as an offset carrier system.4/5/ This is the present day ARINC offset carrier system used by the airlines for operational control. This system has had problems with distortion.4/ This has occurred when in or near the "cone of silence" of one station and also receiving one or more weak signals with phase delay from other sites. Also, some current airline receivers have squelch circuits that do not open when receiving equal amplitude signals from two sites with offset frequencies on the plus and minus side of zero.6/ This dead spot caused by the squelch circuits is being investigated. One solution currently being used to eliminate this dead spot is to adjust the signal to noise squelch higher than the rf carrier squelch. This essentially disables the signal to noise squelch eliminating the dead spot, but does add unwanted noise.7/

2/ Brinkley, J.R., Multi-station V.H.F. Schemes, Electronic Engineering, Vol. 22, No. 270, London, August 1950.

3/ Taylor, D.P., The Development of V.H.F. Area Coverage Networks for Civil Aviation Communication, Electronic Engineering, London, March 1950.

4/ Airborne Radio Equipment Symposium, Chapter 1 - (Part 3), Fifth International Air Transport Association (IATA) Technical Conference, Copenhagen, 1952.

5/ Connell, R.S., ARINC's Multicarrier VHF Network System, Cathode Press, Vol. 24, No. 2, 1967.

6/ West, H.R., Aeronautical Radio, Inc., Memo-Letter to Bill Hunter, FAA, dated 1-5-79 with enclosed ARINC in-house paper on the 25 kHz channel offset carrier system.

7/ Martinec, D. (ARINC), information provided by telephone, July 17, 1979.

2.3 U.K. CIVIL AVIATION AUTHORITY OFFSET CARRIER SYSTEMS

The U.K. vhf area communications system evolved from the Climax network in the early 1950s by additions to provide coverage over most of the U.K. Flight Information Region (FIR). Initial networks used 10 kHz offsets with frequency stability of 0.0003 percent in a 180 kHz channel spacing environment. Transmitters and receivers were installed at the same site equipped with cavity resonators to permit use of a common antenna. To avoid intermodulation interference of the form $2f_2 - f_1 = f_3$, a minimum channel separation of 400 kHz with unequal spacing between the three channels was necessary.^{8/}

Problems encountered in the system expansion were: cross modulation and other interference problems prevented the use of more than four channels at a remote site, poor signal to noise ratio of the combined receiver signals, audio distortion caused by combining signals from landlines with different delay times, and low frequency heterodyne tones due to equal offset carrier spacing. This is the same tone $2f_0 - (f_0 + \Delta) - (f_0 - \Delta)$, was noted in the earlier Brinkley tests. With perfect stability and exact offsets a zero frequency results but with 0.0003 percent stability, heterodynes up to 1200 Hz may result. The higher speed turbo-prop and jet aircraft caused these lower frequency tones to increase in frequency due to doppler shift.^{8/}

Air traffic increases caused an increase in the number of traffic control sectors with the result that smaller areas needed single frequency coverage. Thus, the earlier five station system was reduced to three or two station networks. A staggered or asymmetrical offset system was introduced at $f_0 + 10.5$ kHz, $f_0 + 3.5$ kHz, and $f_0 - 10.5$ kHz with stability slightly increased to +350 Hz. With these spacings, the high audio beats were at or above a nominal 7 kHz and no other beats had sufficient amplitude to cause a problem. Common sites for receivers and transmitters were abandoned with the advent of 50 kHz spacing and a separation of 2.5 miles was usually adequate to avoid intermodulation effects. Due to frequency limitations, some third order intermodulation such as $2f_2 - f_1 = f_3$ and $f_1 - f_2 + f_3 = f_4$ forms occurred.^{8/}

For 25 kHz channel spacing, a +7.5 kHz and zero offset carrier system is now used in the U.K. An asymmetrical system of +7.5 kHz, +2.5 kHz and -7.5 kHz was tried but produced 5 kHz in some airborne receivers with inadequate high audio band cutoff. It is intended to try the +2.5 kHz asymmetric system in the near future and if there are no adverse reactions due to the 5 kHz beat, a four station system gradually will be introduced with +7.5 kHz and +2.5 kHz offsets. Stability of the transmitters is being maintained within 0.3 parts per million. Flight tests have demonstrated that the low frequency beat note (normally zero with perfect stability and no doppler shift) did not impair satisfactory reception provided 0.3 parts per million or better transmitter stability was maintained.^{8/}

^{8/} Hayes, D.W., unpublished paper, UK VHF Area Communication System, Civil Aviation Authority, National Air Traffic Services (NATS), Telecommunications Division, London, August 1979.

A method for improving performance of A.M. quasi-synchronous radio telephone systems has been investigated by P.F. Raven at the Electricity Council Research Centre. This approach introduces an intentional delay into the modulation paths of all but the initial transmitter. It does create an echo effect at all times and would thus not be useful in solving current FAA problems. It is referenced because frequency congestion is a continuing problem. U.K. land mobile services have now reduced channel spacing to 12.5 kHz and the band width does not permit normal offset carrier operation, but instead quasi-synchronous transmission is used with offsets of only a few hertz.^{9/} This procedure is not necessary in the current U.K. offset carrier system for 25 kHz.

2.4 OFFSET CARRIER SYSTEM DESIGN THEORY

Amplitude modulated (AM) offset carriers input to an AM receiver produce the same types of sum and difference terms as in a single carrier system, but additionally the sum and difference terms between the two or more carriers are produced. This assumes the carrier offsets and modulation are within the receiver passband. The modulation frequencies will be detected and will sum together in the receiver output to provide the identical frequencies with an amplitude determined by the input amplitudes and any phase differences that may exist. For example, with $A_1 \sin \omega t$ and $A_2 \sin (\omega t + \theta)$ as modulation inputs, the output will be of the form $K [A_1 \sin \omega t + A_2 \sin (\omega t + \theta)]$ which has an amplitude range from $k(A_1 + A_2)$ if $\theta = 0^\circ$ to zero if $A_1 = A_2$ and $\theta = 180^\circ$.

The phase difference θ is really a function of the delay time ΔT between the two modulation signals. For voice modulation, while ΔT may be constant at any given instance, θ will be different for each frequency component and distortion can result. This phase delay difference should be kept well below 90° at the highest modulating frequency.^{10/} For the 2550 Hz upper audio band limit of the NAS vhf communication system, this corresponds to a time delay of less than $98.0 \mu s$ ($1/4 \times 1/2550$). The ΔT is made up of two portions: the modulation delay between transmitters and the propagation time delay due to different path lengths. The two signal case with near equal amplitudes will be the worse case for distortion caused by delay differences since the maximum change in resultant amplitude can occur. In general, this can occur between two stations (roughly equidistant for equal output power) and also in the near vicinity of one of the stations, but in the null region of the antenna.

^{9/} Raven, P.F., A Method of Improving Reception with VHF Mobile Radio Telephones Using Multiple Transmitters and Audio Delay, IERE, VII, London, 1978, pp 19-28.

^{10/} Jakes, William C., Jr., editor, Microwave Mobile Communications, John Wiley & Sons, New York.

The carrier offsets should be greater than the audio bandwidth so that the heterodyne produced at the carrier difference frequency lies above the audio bandpass of the receiver. Further, the offset should be at least twice the audio bandwidth for two signals that will be received simultaneously.^{10/} The U.K. system essentially follows this offset separation rule since even in the asymmetric case of +7.5 kHz and +2.5 kHz offsets, the lowest difference is 5 kHz which is just twice the audio upper limit. ARINC does not follow the rule since only 4 kHz offsets are present between many of their adjacent stations. Distortion in the higher audio frequencies could be experienced, but no reports of this have been found.

In a three station system, evenly spaced offsets about a center carrier frequency where all three signals are received can produce a heterodyne $2f_2 - f_1 - f_3$, or in terms of f_0 : $2f_0 - (f_0 + \Delta) - (f_0 - \Delta)$ which is equal to zero if no drift or doppler shift occurred. For subsonic aircraft a doppler frequency shift of about 100 Hz can be produced at 130 Mhz.

$$450 \text{ kts} = 231.5 \text{ m/s} \quad v_c = 3 \times 10^8 \text{ m/s}$$

$$130 \times 10^6 \left(\frac{231.5}{3 \times 10^8} \right) = 100.32 \text{ Hz} \quad (1)$$

Hence up to a 400 Hz beat could be produced by doppler shift alone if the direction of aircraft travel were directly toward the f_2 station and away from f_1 and f_3 . This would add to any instability drift and can introduce a low frequency beat above 300 Hz. U.K. tests have demonstrated satisfactory operation under worse case conditions if the transmitter stabilities are maintained at 0.3 parts per million (40 Hz) or better.^{8/}

How to select or combine the downlink signals remains an area of concern. Combining all audio received via telephone lines through a mixing amplifier can be used, but distortion will result due to any audio delay differences between lines which can cause an echo. Further, equal signals received from remote sites with sufficient differential propagation delay will cause distortion. Also, the use of manual selection of the best audio signal is to be avoided since it places a workload on the controller that could be eliminated if an acceptable automatic method can be found. No good method has been found to cure all the faults possible. U.K. systems use group phase equalizers in some lines to eliminate airborne audio distortions ^{8/}, and this would also ensure good telephone line mixing reception of the downlink if no differential propagation delay existed. Voting combiners have also shown promise.

3.0 APPLICATION OF OFFSET CARRIER SYSTEMS TO FAA AIR-GROUND COMMUNICATIONS

The sites to be considered during the study are Remote Center Air-Ground (RCAG) or Backup Emergency Communication (BUEC) sites. The groups to be considered are (with location, site elevation, antenna height, and center designation):

Uvalde, TX - 29° 12'54"N 99° 44'22"W 938 ft MSL 30 ft antenna
Rock Springs, TX - 30° 04'45"N 100° 20'30"W 2,347 ft MSL 46 ft antenna
Houston high altitude sector coincident with RSG-L (98)
frequency 132.4 Mhz, FL230-FL450

Aspen, CO - 39° 09'07"N 106° 49'10"W 11,212 ft MSL 21 ft antenna
Grand Mesa, CO - 39° 05'30"N 108° 13'24"W 10,025 ft MSL 37 ft antenna
Hayden, CO - 40° 28'00"N 107° 13'00"W 7,432 ft MSL 35 ft antenna
Denver low altitude sector 12, frequency 128.5 Mhz, surface to FL310

Delta, UT - 39° 23'54"N 112° 30'06"W 4,755 ft MSL 40 ft antenna
Francis Peak, UT - 41° 02'01"N 111° 50'16"W 9,515 ft MSL 55 ft antenna
Salt Lake City low altitude sector 30, frequency 134.8 Mhz, surface to FL320

Francis Peak, UT - 41° 02'01"N 111° 50'16"W 9,515 ft MSL 55 ft antenna
Delle, UT - 40° 50'53"N 112° 47'59"W 6,400 ft MSL 35 ft antenna
Salt Lake City high altitude sector 41, frequency 132.55 Mhz, FL330 and above

These sites are separated by the following distances (as scaled directly from map locations with no corrections made for elevation):

Rock Springs - Uvalde, TX	60 nm.
Grand Mesa - Aspen, CO	60 nm.
Aspen - Hayden, CO	82 nm.
Hayden - Grand Mesa, CO	95 nm.
Delta - Francis Peak, UT	102 nm.
Francis Peak - Delle, UT	45 nm.

Target Acquisition contours and Line of Sight contours were requested by the FAA from the Electromagnetic Compatibility Analysis Center (ECAC) and have been provided for the four configurations. These plots, and energy density plots will be used as necessary in the remaining portion of the study. From an initial review of the target acquisition contours, it appears that any problems for the two high altitude sectors will not be due to inability to "see" an aircraft from the sites based on pure geometric considerations using 4/3 earth radius corrections. However, for the low altitude sectors, there are sizeable areas that are not seen by any of the sector remote sites. Thus, while improvement in coverage can be expected with the use of offset carriers, the low altitude sectors will probably still have coverage holes.

The contours for the selected sites are included as an appendix. Areas not included in a contour from any of the sector sites have been shaded for clarity. Sites located outside of the controlled sector have the advantage that some of the possible propagation delay distortion area (discussed in 3.a. following) is located outside the sector. Examples are Grand Mesa for Denver sector 12 and Francis Peak-Delta for Salt Lake City sector 30. Additionally, the Salt Lake City high altitude sector 41 uses Francis Peak-Delle as remote sites, but has adequate coverage from Francis Peak-Delta. This last combination could reduce the delay distortion if necessary and also serve as a backup configuration if an outage occurred at Delle.

a. Delay Problem Areas

Since a differential time delay of 98.0 μ s or more can cause 90° or more phase shift at 2550 Hz, the regions where this can occur were analyzed. The propagation path difference that will cause 98.0 μ s delay is 16 nm.

$$\begin{aligned}\Delta D &= (3 \times 10^8)(98.0 \times 10^{-6}) = 2.94 \times 10^4 \text{ m} \\ &= (2.94 \times 10^4)(5.4 \times 10^{-4}) = 16 \text{ nm}\end{aligned}\quad (2)$$

Thus, for differences in air to ground terminal distances of 16 nm or more, delays of 98 μ s can occur. All the given site configurations have separations that exceed 16 nm.

A hyperboloid of two sheets is the locus of points P(x,y,z) such that the difference in distance from P to two fixed points is a constant. For two points F₁(-c,0,0) and F₂(c,0,0) and a constant difference of 2a, the equation of the hyperboloid is

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1, \text{ where } b = \sqrt{c^2 - a^2}\quad (3)$$

A sketch of the surface is shown in Figure 1 for positive values of z which represents altitude.

The intersection of the surface and x-y plane (z=0) is a hyperbola $\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$ as shown in Figure 2.

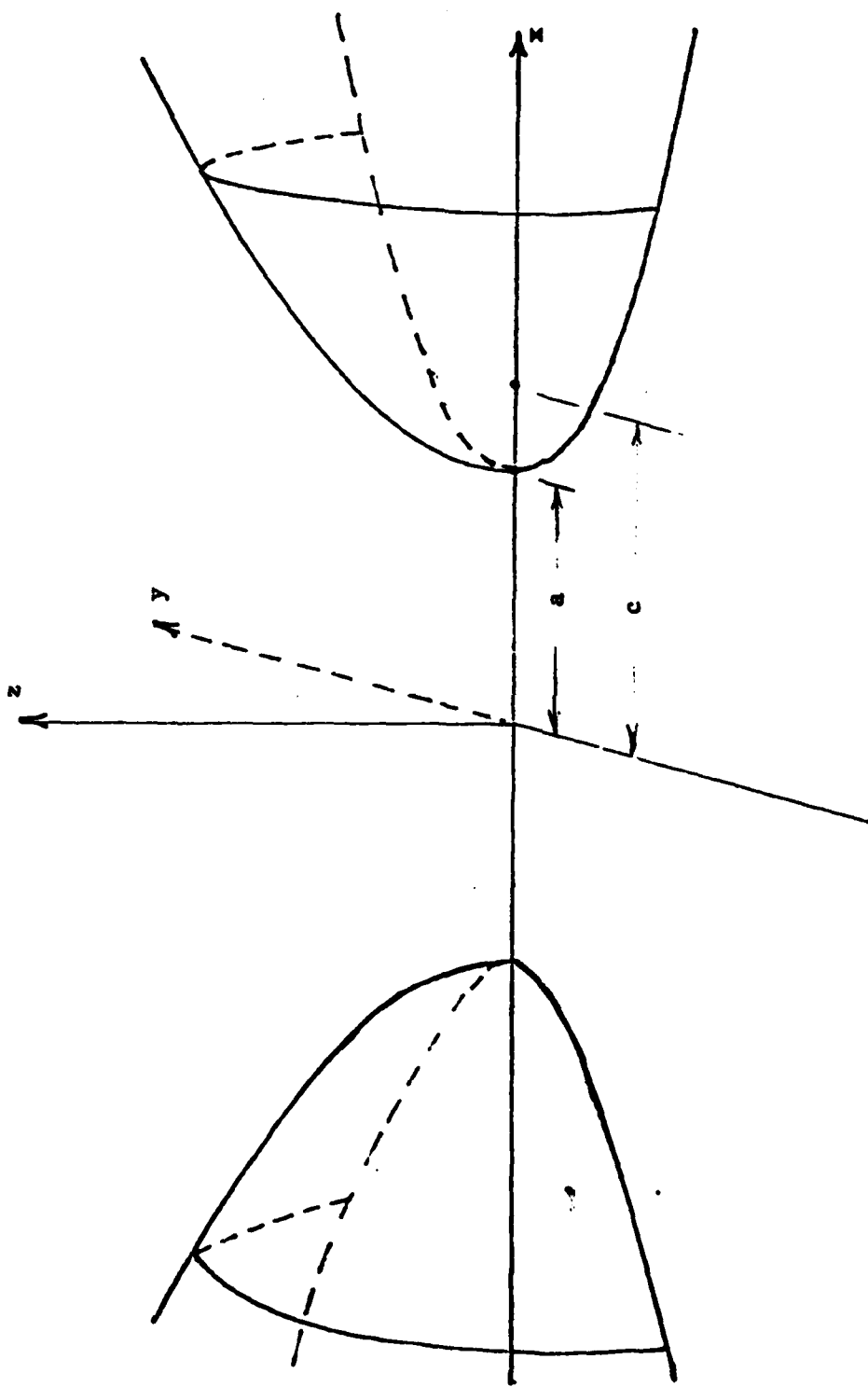


FIGURE 1

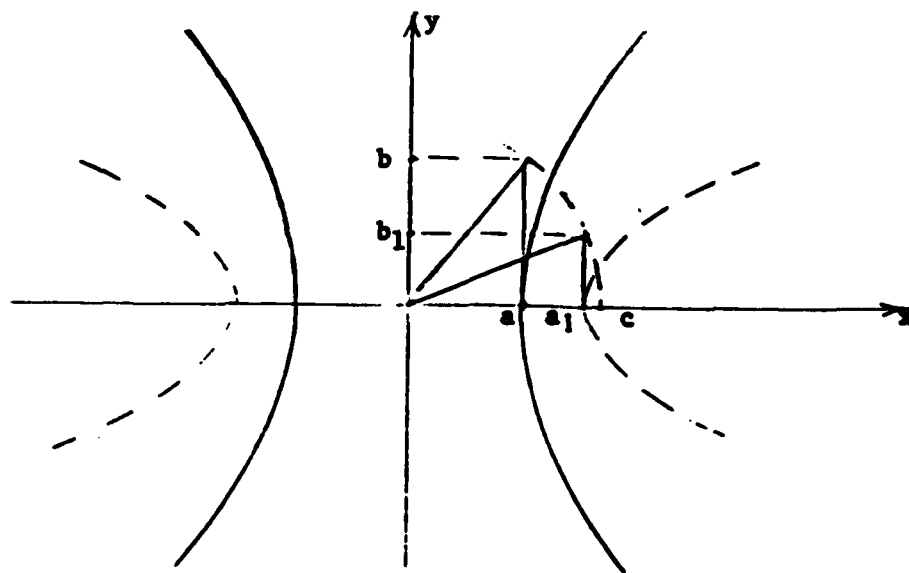


FIGURE 2

As $a > c$, $b > 0$ and the hyperbola will narrow down as shown by the dotted curves sketched for $a_1 > a$, $b_1 = \sqrt{c^2 - a_1^2} < b$. The hyperboloid also narrows down. The point is, if $2a$ is chosen to equal the path difference (16 nm) necessary to cause a 90° phase shift at 2550 Hz, the resulting equation defines a limiting hyperboloid with all others for $\Delta D > 16$ nm being narrower and within the $\Delta D = 16$ surface.

For the four given configurations, all sites are separated by more than 16 nm (minimum separation is 45 nm at Francis Peak-Delle) and the delay exists for distortion to occur. Note that the delay surfaces extend away from the area between the two stations, thus the normal area of equal signal strength does not have sufficient propagation delay to cause distortion. Another area where equal signal strength can occur is roughly over one station in the antenna gain notch or "cone of silence" area. All the omnidirectional antennas in use by the FAA exhibit this notch, thus the possibility exists for distortion. Distortion due to the "cone of silence" or null in the antenna pattern should occur when an aircraft is almost directly over the remote site. Distortion is possible in both aircraft and ground reception, but since the ground transmitting and receiving antennas are separated, one aircraft position may only cause downlink distortion and a different position cause uplink distortion.

Other distortion areas may exist due to lobes in the horizontal gain patterns due to induced currents in mounting poles. Further, the aircraft antenna gain pattern must also be considered. That the delay conditions exist sufficient to cause distortion is known. How much the two signal strengths can differ from equality and still cause noticeable distortion is not known. Where the areas of equal or near equal signals are located will have to be determined on a site pair by site pair basis with little universal application.

The telephone lines linking the receiver/transmitter sites are another source of distortion due to delay and noise. A noisy line, when it exceeds the tolerances, may be replaced by a spare or maintenance accomplished to adjust to within tolerances. The delay of the lines presents a different problem. The two or more lines must have the same delay on each line for a given frequency although the delays for two different frequencies do not have to be the same. In other words, the envelope delays should be the same for each line pair and so should the attenuation. Since the line characteristics vary, methods to automatically adjust the delay and attenuation need to be investigated along with how to best combine the received signals to avoid the echo or barrel effect.

b. Offset Spacing Problems

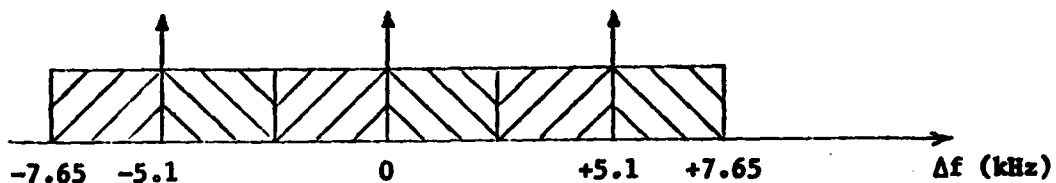
It is expected that some general aviation vhf receivers will have audio passbands that do not cut off as sharply and at as low a frequency as do the receivers meeting the ARINC 566A and 716 characteristics. Thus, the offset carrier spacing should be approximately 5 kHz to avoid the same problems that the U.K. had with older receivers. A sample of aircraft receivers, to include airline and general aviation, will be investigated for audio bandwidths and other pertinent characteristics.

The "U.S. National Aviation Standard for the VHF Air-Ground Communications System", FAA Order 6510.4 dated 11/11/77 states in paragraph 3.1.2.5 that 99% of the transmitted power output shall fall within ± 7.5 kHz of the assigned carrier frequency under all modulation conditions. An interpretation that assumes the assigned carrier frequency means the channel or center frequency would not allow twice the audio bandwidth separation between offset carriers since three audio bandwidths would be required from the zero offset carrier: two bandwidths for the carrier separation plus an additional carrier sideband.

$$3 \times 2.550 = 7.65 \text{ kHz} > 7.5 \text{ kHz}$$

(4)

Thus, the initial spacing shown below does violate the ± 7.5 kHz channel bandwidth, but meets the ± 8.0 kHz FCC rule.



The high audio frequency heterodyne beat would be nominally at 5100 Hz. Even with a 0.0005% stability (650 Hz at 130 Mhz), the worst case drift would place the beat at 3800 Hz. Both ARINC characteristics 566A and 716 required a sharp cutoff above 2500 Hz with at least a 20 db attenuation to occur at 3750 Hz, thus even the worst case high audio frequency beat should be no problem with airline receivers. Other receivers not built to the ARINC characteristics may have problems with the 5100 Hz beat.

Low audio beats caused by the fourth order term $2f_2 - f_1 - f_3$ can be a problem with the current FAA stability of 0.0005% (650 Hz at 130 Mhz). While nominally zero, up to a 2600 Hz beat is possible if f_2 drifts high and both f_1 and f_3 drift low. Lower values of drift can put the beat anywhere in the 300-2550 Hz audio band. This type of low frequency beat has been found objectionable in the U.K. tests and ± 40 Hz stability transmitters are used now. While a ± 40 Hz stability seems indicated, tests should be conducted to ascertain what is the level of this low beat note compared to the audio signal. This would allow assessment of the necessity for increased stability.

How to provide a good quality audio output to the controller may be a difficult problem. Audio comparators have been tried and found not to be completely satisfactory. Lock up on a noisy line, switching while a message was being received, and failure to handle all the barrel effect have been some of the complaints. Combining tests should be conducted at a test facility without interference with normal ATC operation. However, a controlled experiment may be necessary in a live environment to analyze a given set of conditions.

Equalization of the telephone lines and a voting system may be a solution, but a more extensive review is needed to search for hidden problems and other possible solutions.

4.0 CONCLUSION

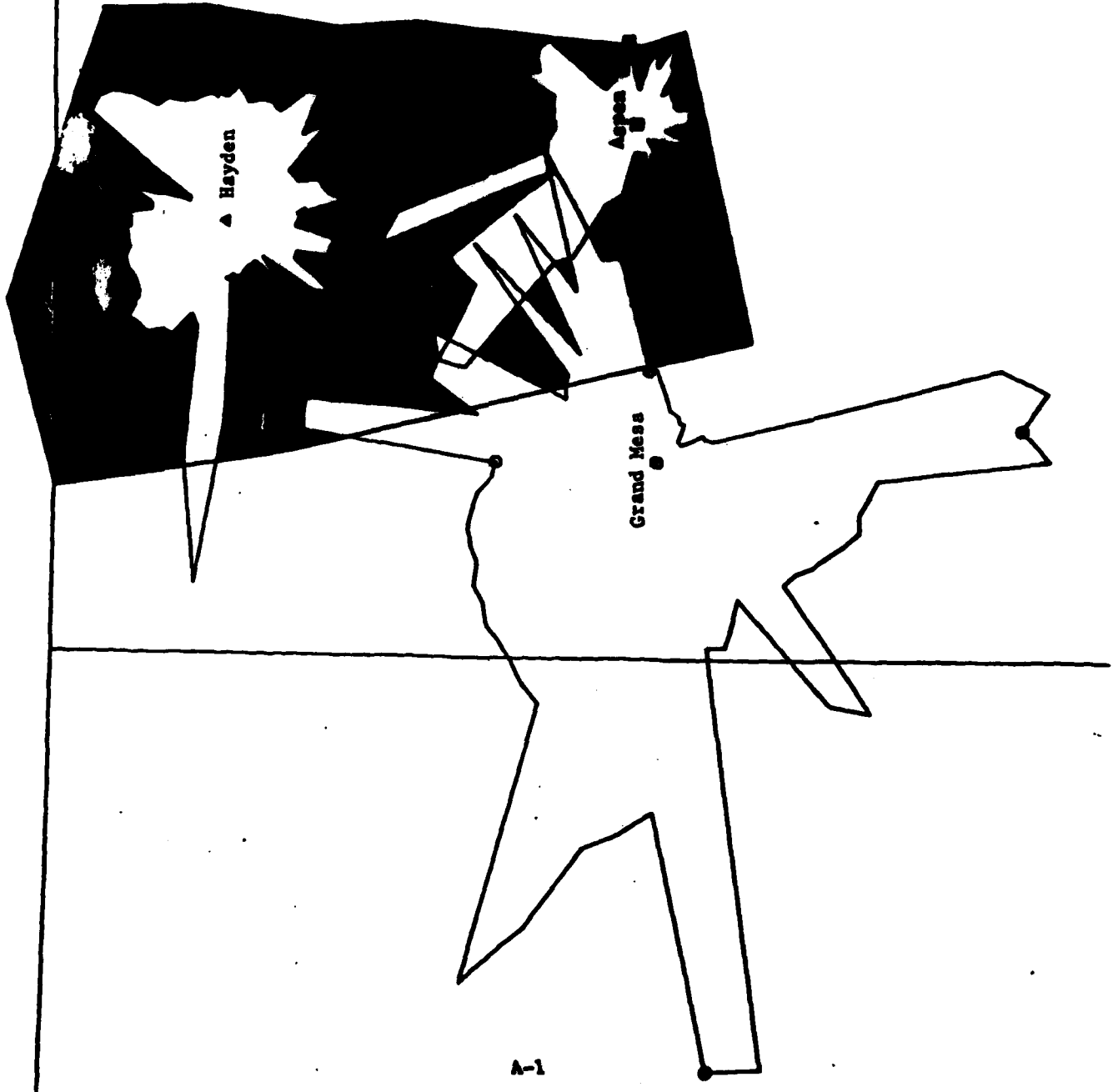
A conclusion as to what the offset carrier system should be for FAA ATC operation is not possible at this time. That offset carrier systems work has been proven by the U.K., ARINC, and land mobile systems. None are perfect and compromises have been made. An FAA system also will have compromises.

Controller workload may be decreased if an acceptable multiple site combining system can be developed. If automatic combining is not feasible, the controller would have to select the best receiver site to avoid the barrel effect when it occurs.

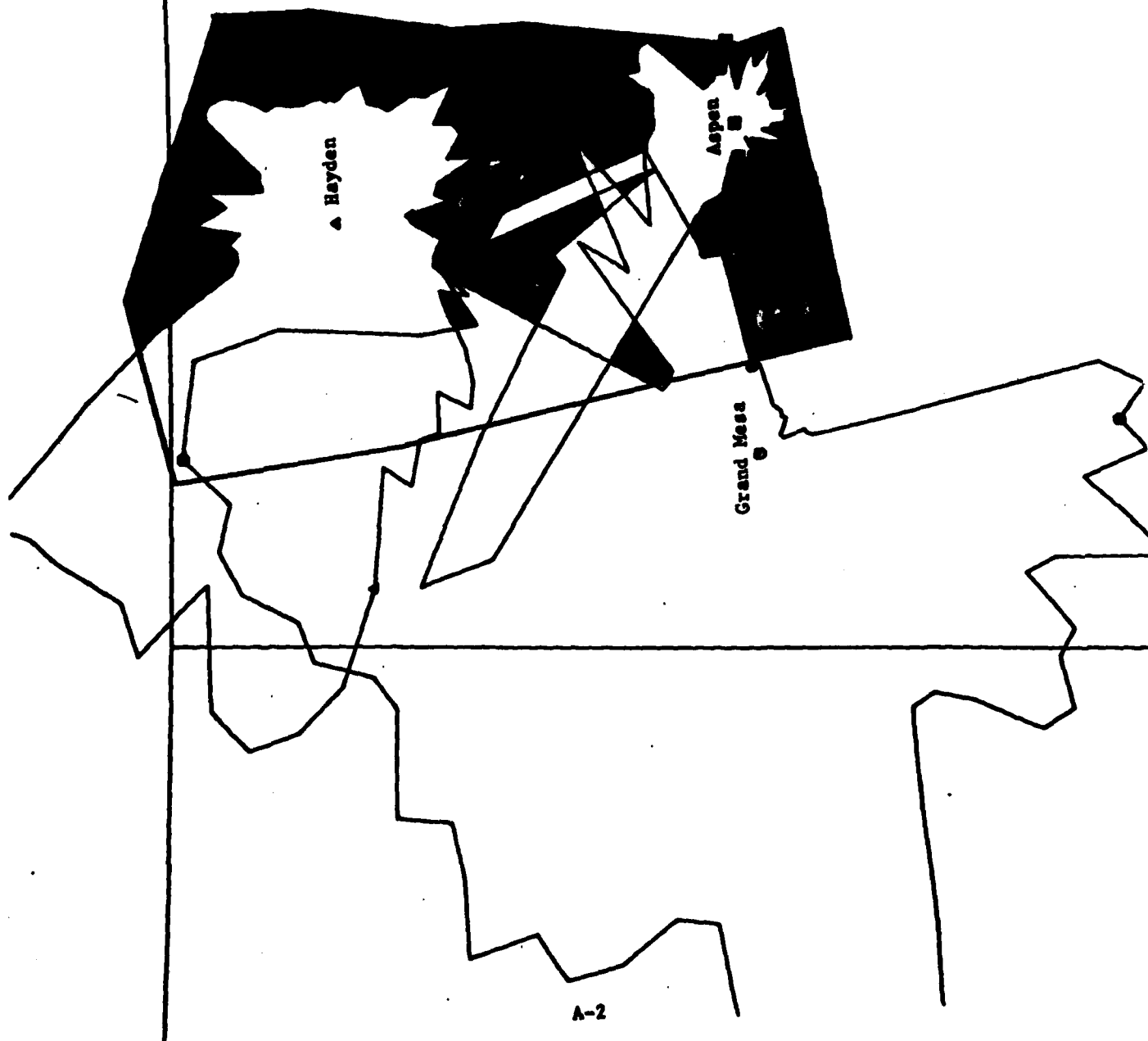
Depending on the aircraft radio type, the pilot may hear a high audio beat note. Low audio beats also are possible unless the ground transmitters are made more stable. The distortion caused by excessive audio delay would be annoying, but may clear up shortly as the flight continued. No assessment as to whether the offset carrier operation is worth the possible added audio beats and distortion can be made at this time.

APPENDIX A

Denver
Sector 12 (low)
5,000 ft TAM contours
Aspen □
Hayden ▲
Grand Mesa ○



Denver
Sector 12 (low)
10,000 ft TAM contours
Aspen □
Hayden ▲
Grand Mesa ○



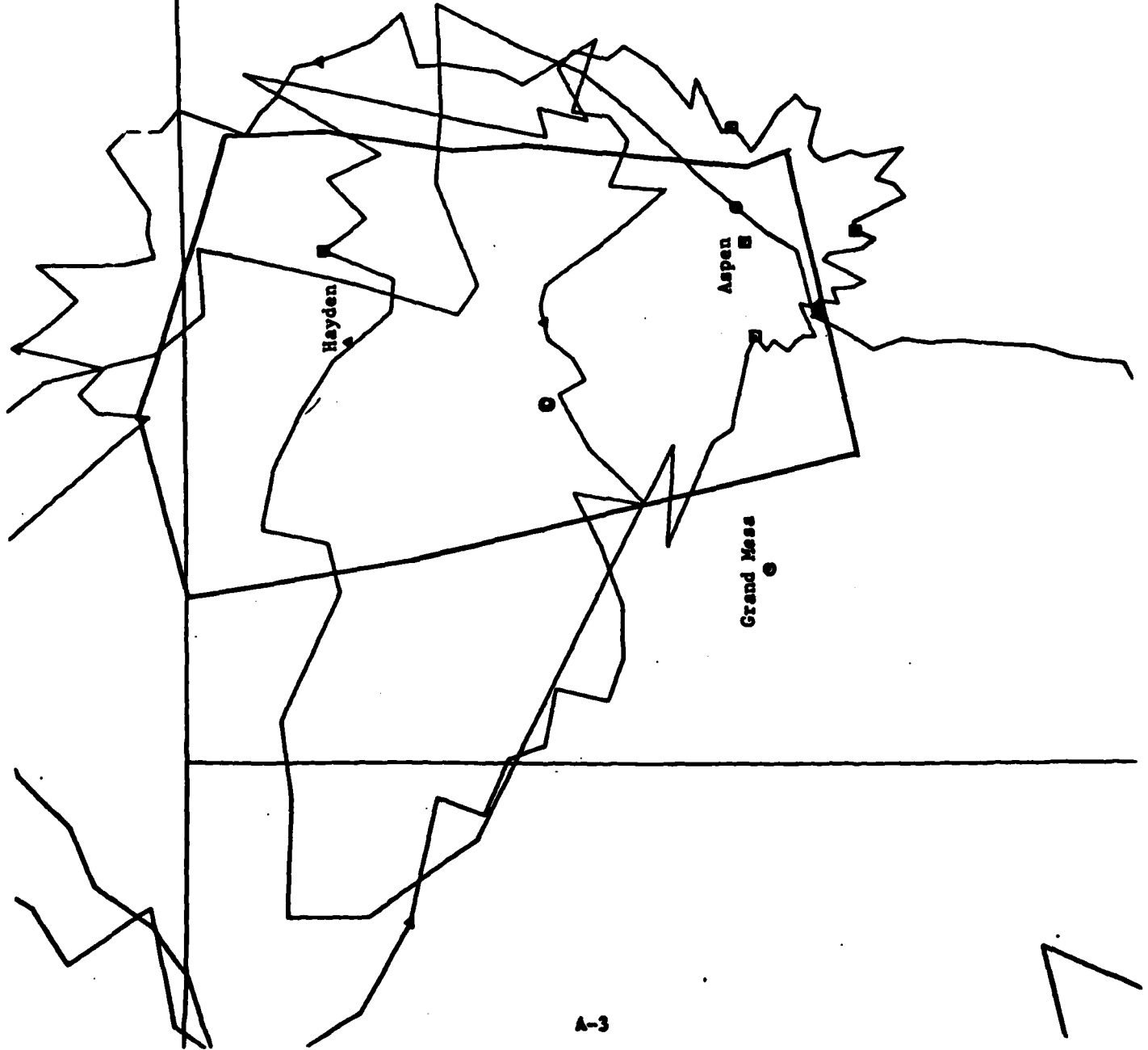
Denver
Sector 12 (low)

15,000 ft TAM contours

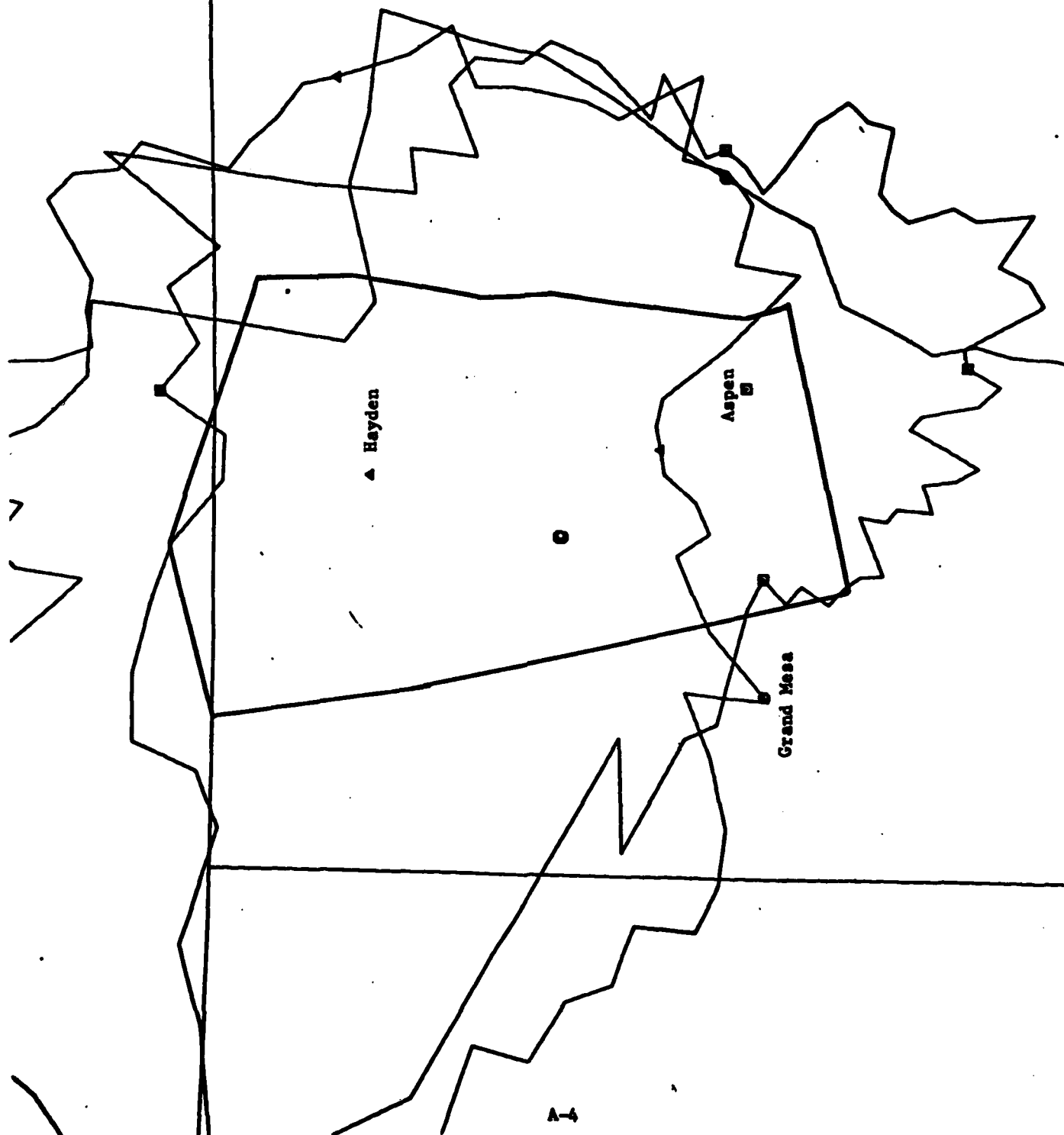
Aspen □

Hayden ▲

Grand Mesa ○



Denver
Sector 12 (low)
20,000 ft TAM contours
Aspen □
Hayden ▲
Grand Mesa ○

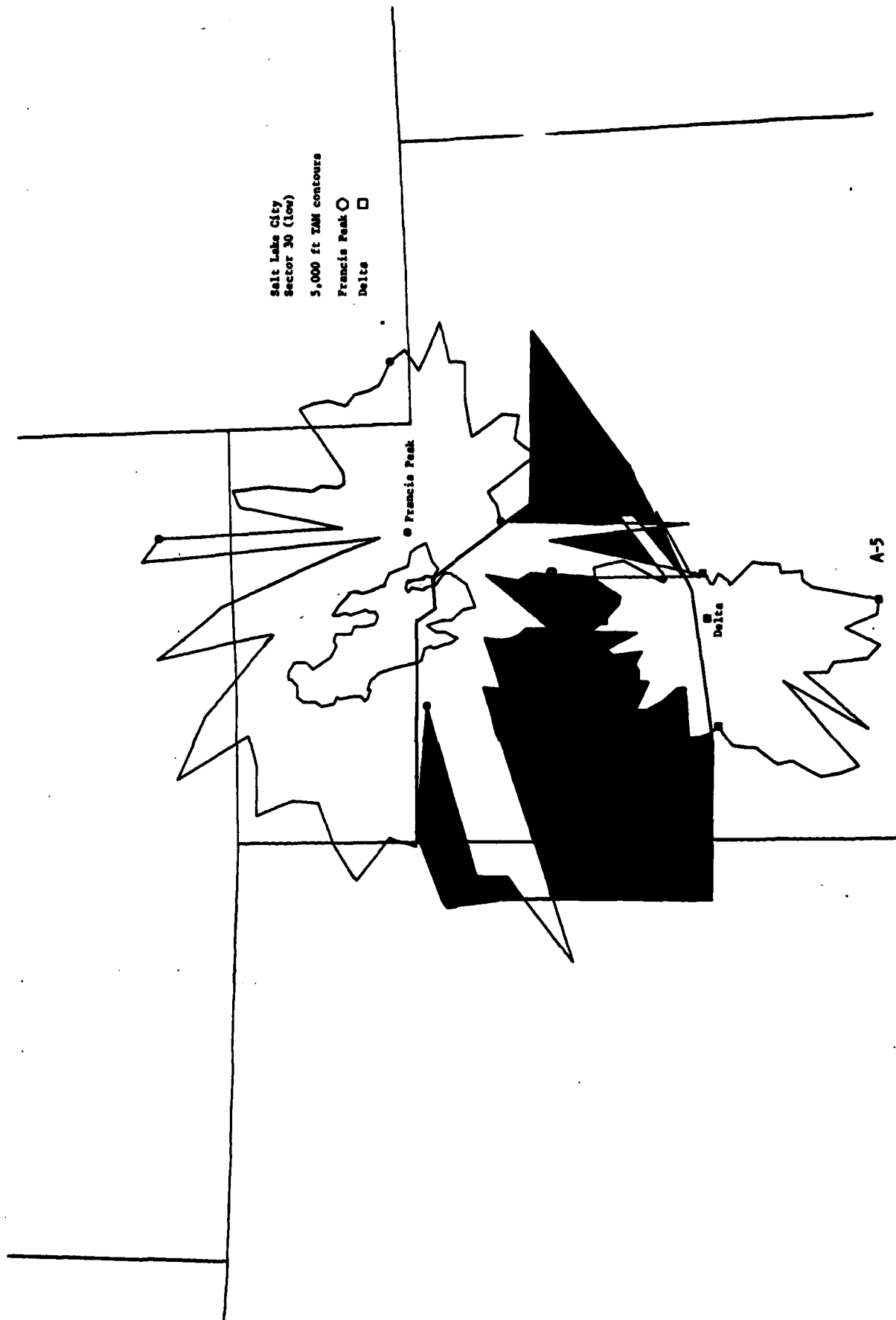


Salt Lake City
Sector 30 (low)

5,000 ft TAM contours

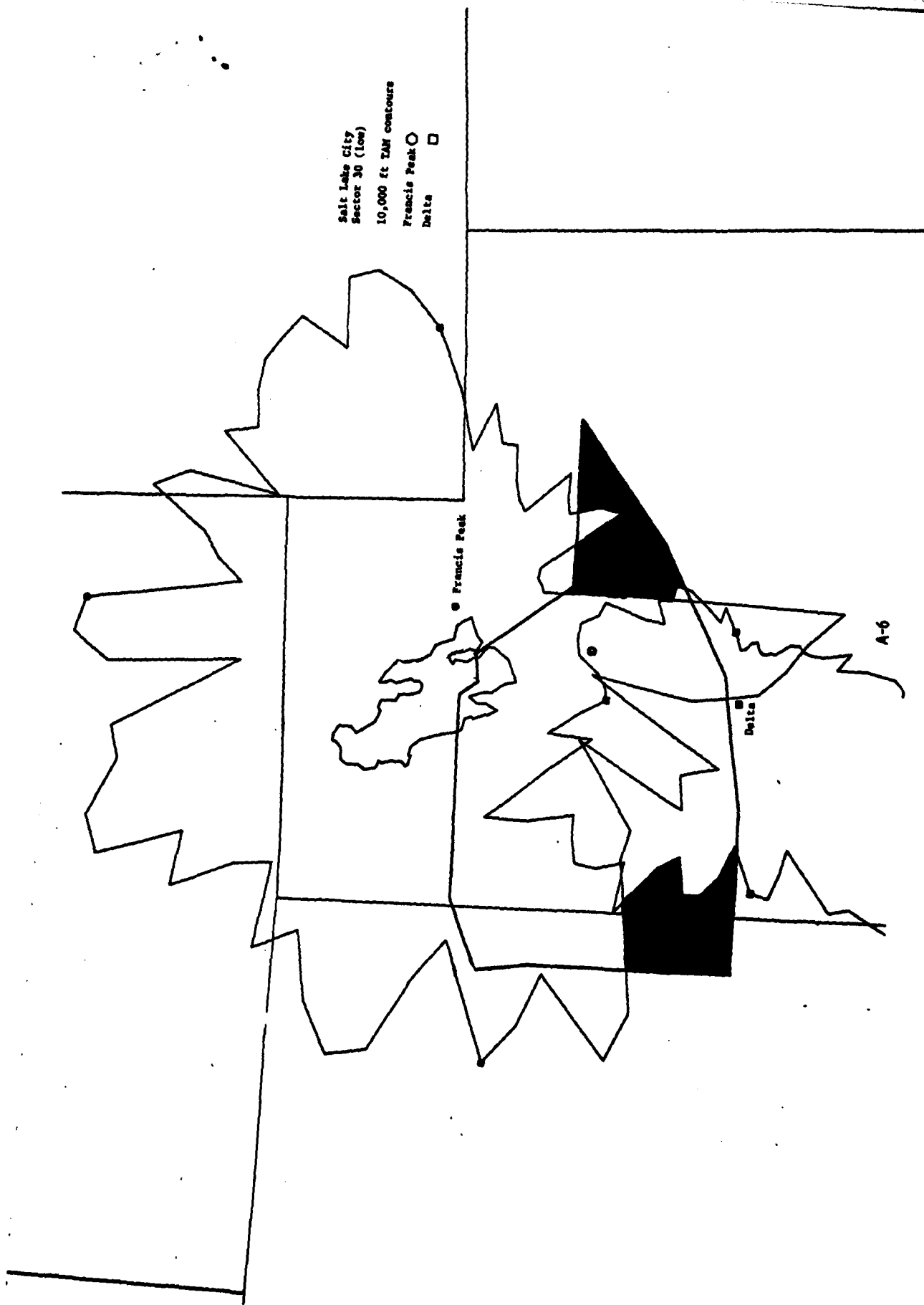
Francis Peak ○

Delta □



A-5

Salt Lake City
Sector 30 (low)
10,000 ft TAD contours
Francis Peak ○ □
Delta

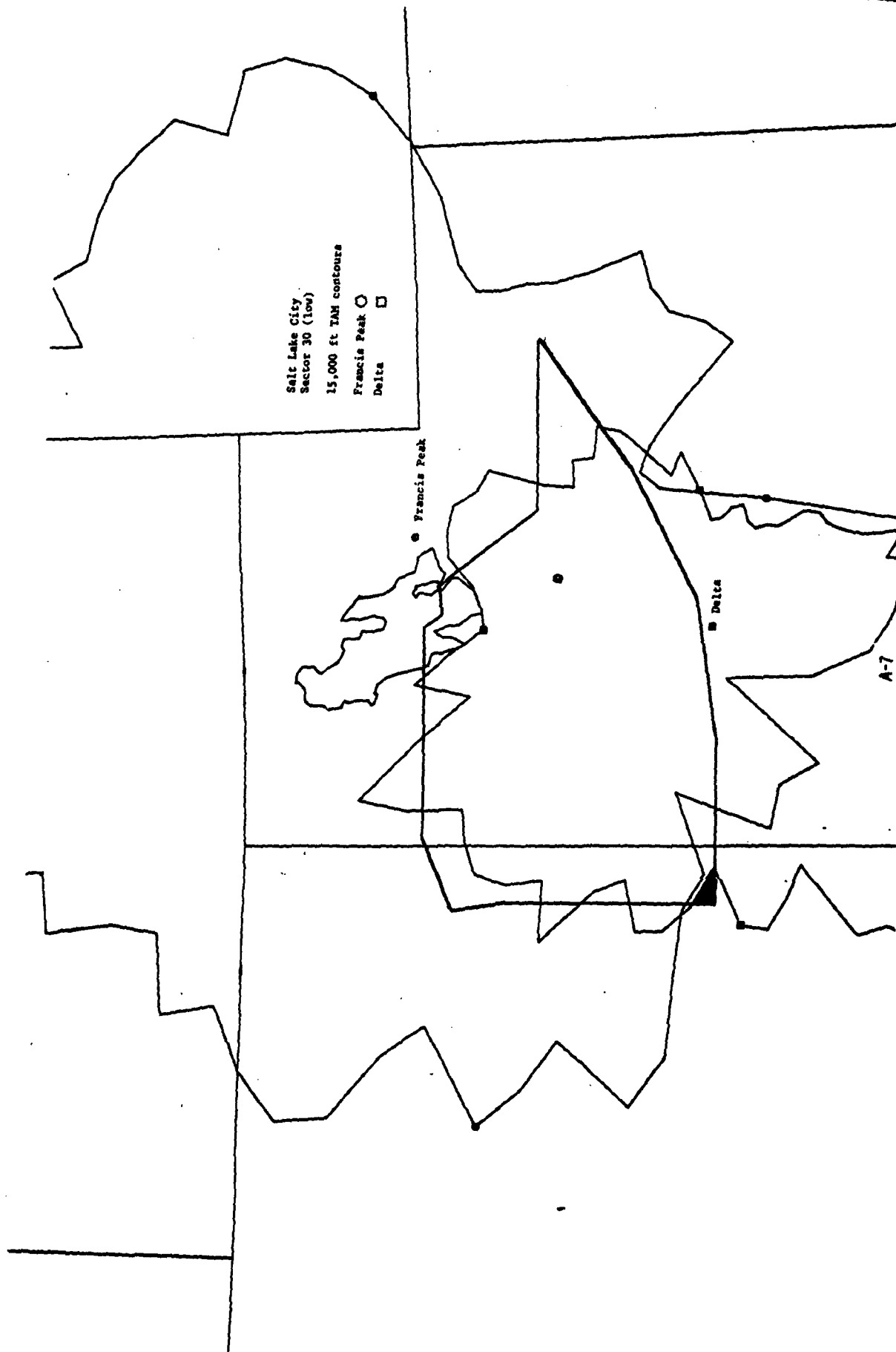


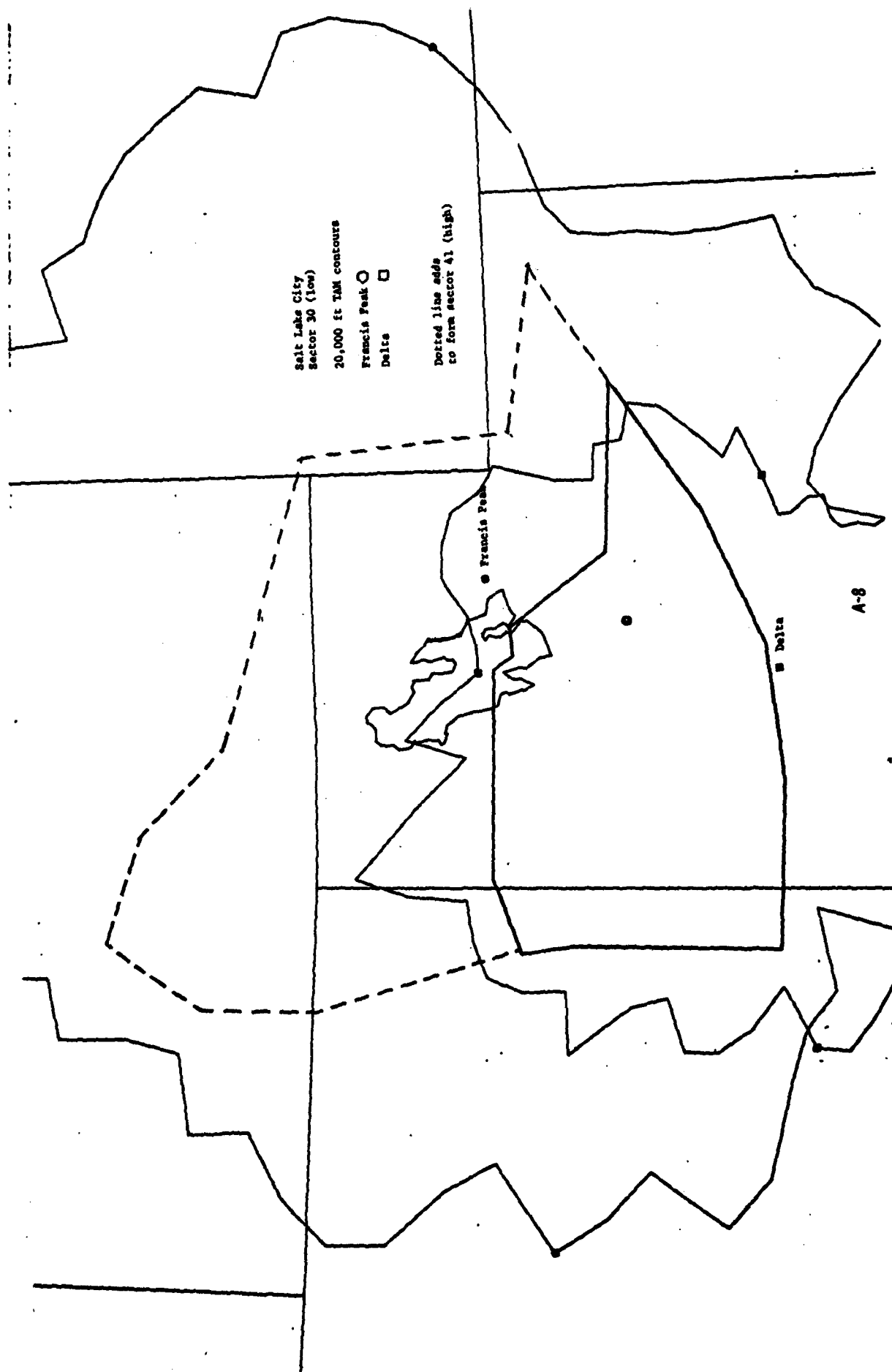
Salt Lake City
Sector 30 (low)
15,000 ft TAN contours
Francis Peak ○
Delta □

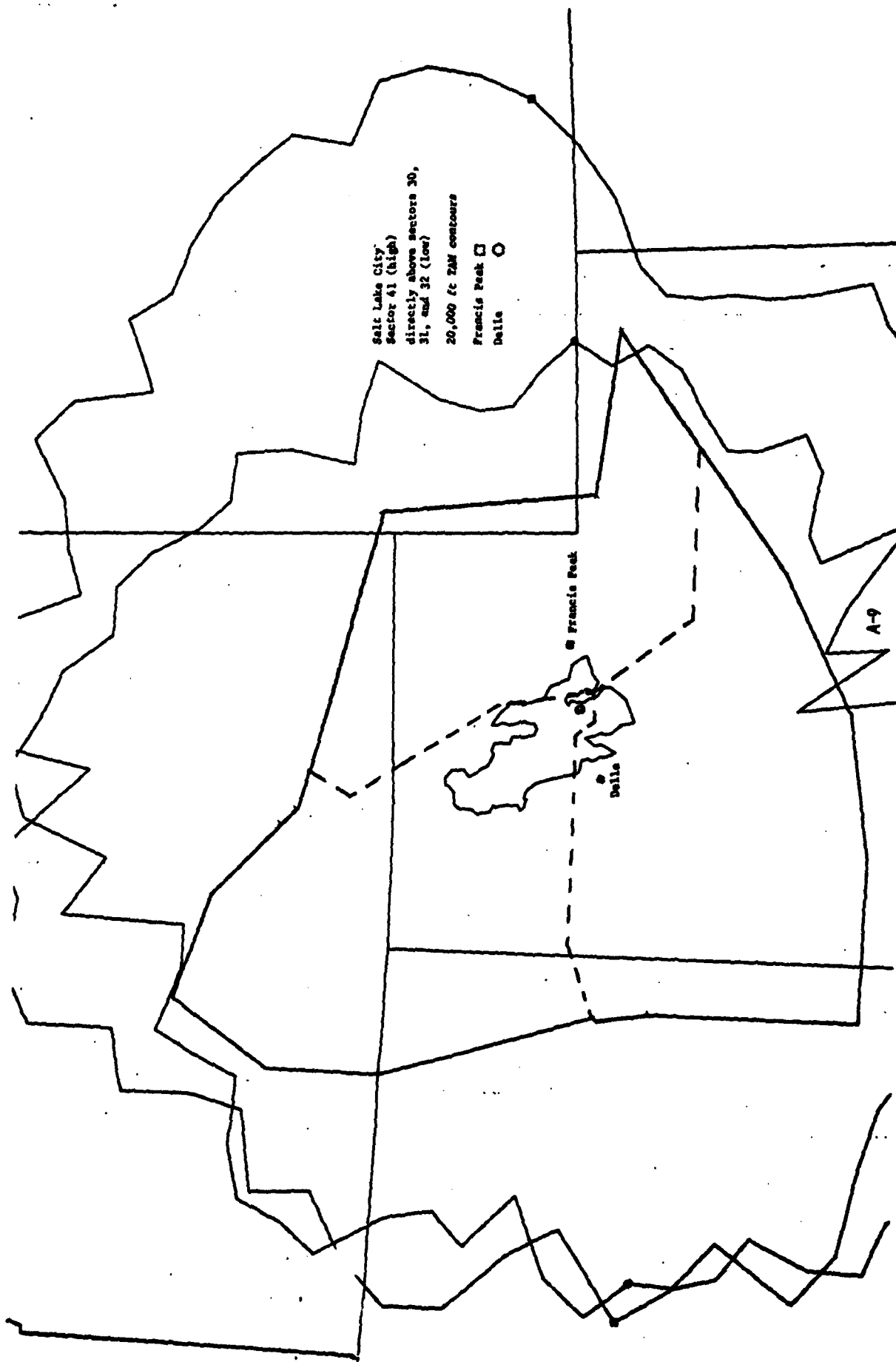
● Francis Peak

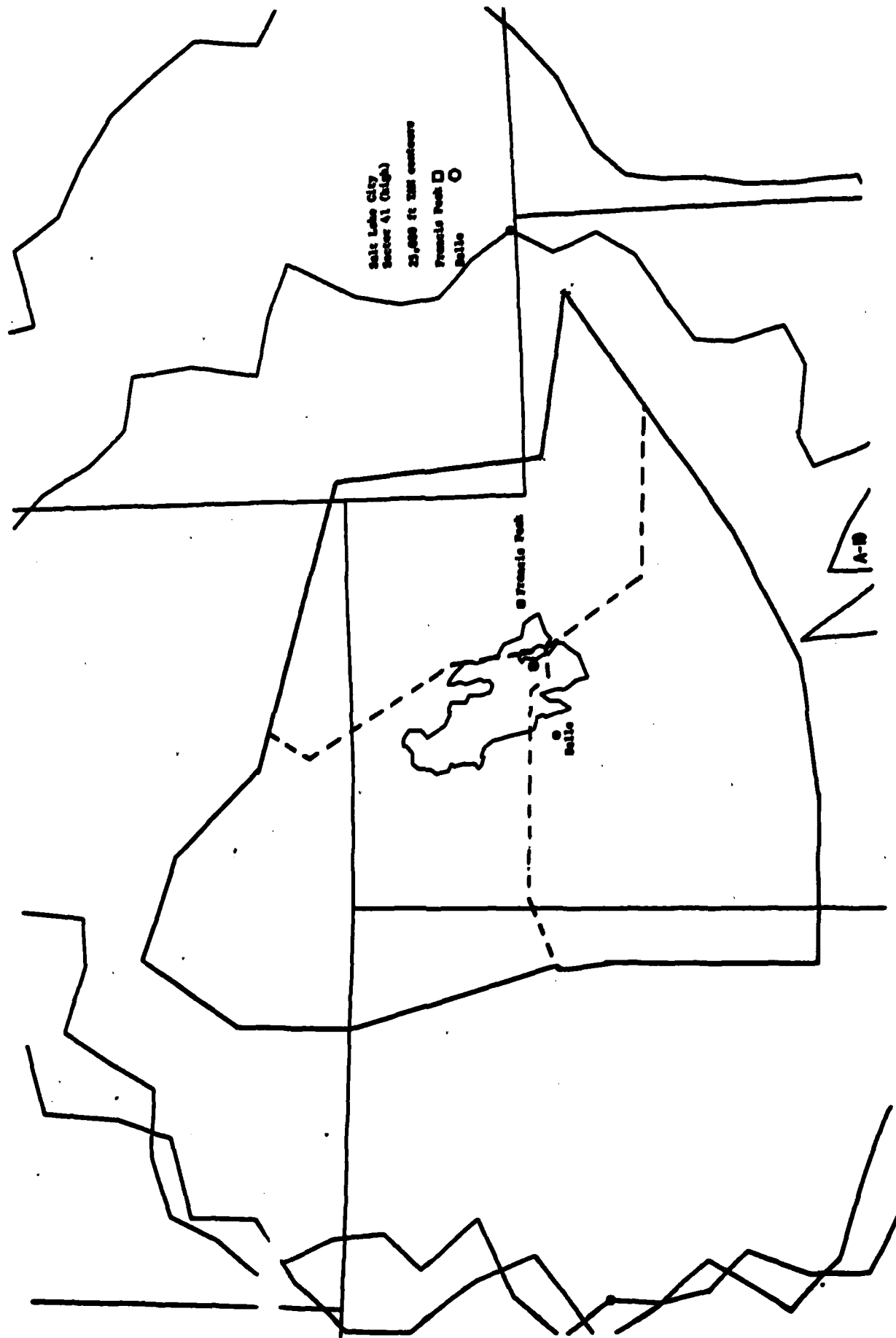
■ Delta

A-7







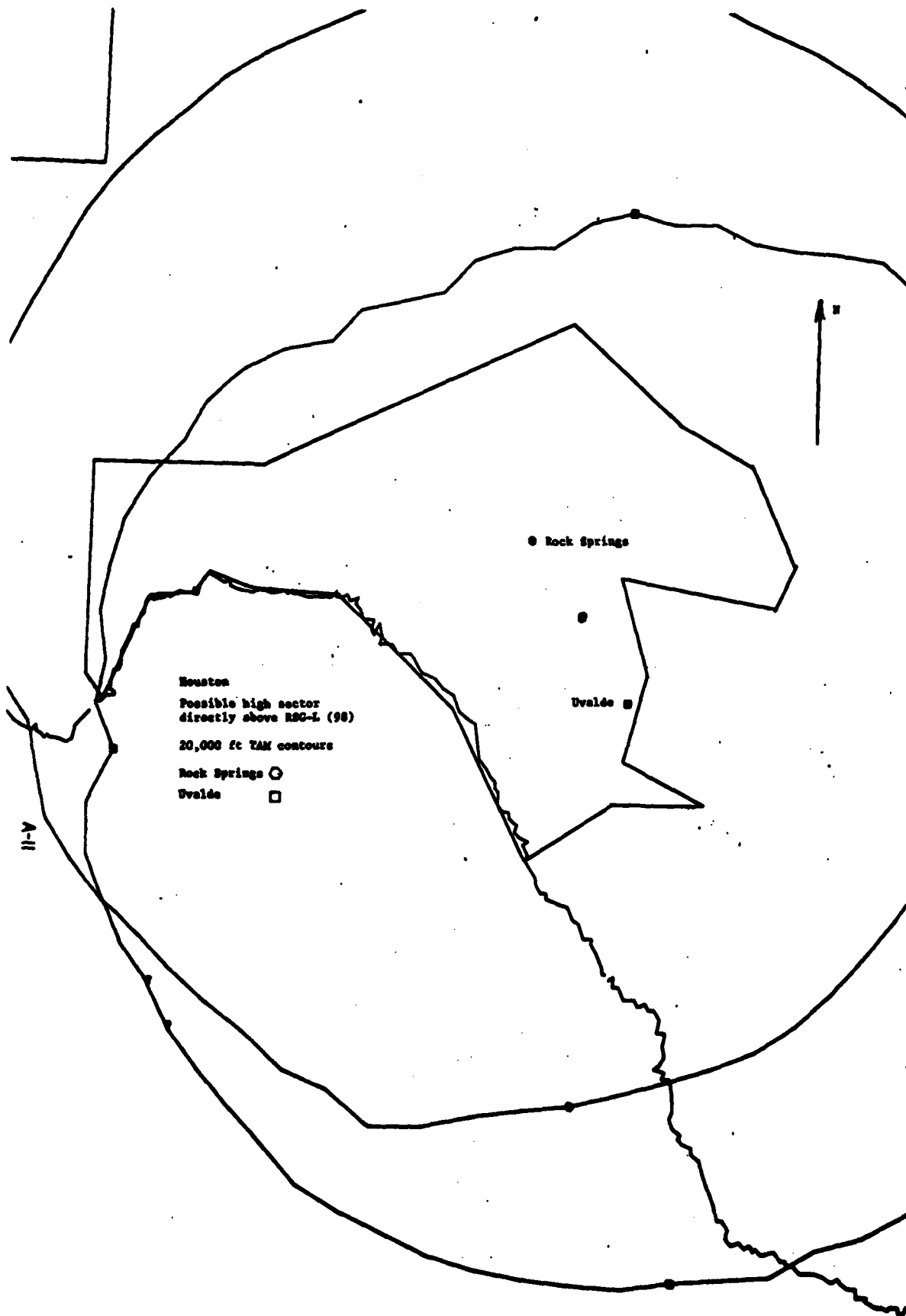


Salt Lake City
Sector 41 (Salina)
25,000 ft 1:250,000 contour
Francis Peak □
Salina ○

Francis Peak

Salina

A-B



APPENDIX B
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DA
FILM
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